Evaluation of Current and Wave Measurements from a Coastal Buoy

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Abstract-**The Chesapeake Bay Interpretive Buoy System (CBIBS) collects real-time measurements of currents and directional waves from a series of small buoys designed for coastal regions. The buoys use an AXYS Technologies TRIAXYS directional wave sensor and a downward looking 1 MHz Nortek Aquadopp Profiler for current profiles. In this experiment, a bottom mounted Nortek acoustic wave and current (AWAC) profiler was deployed next to one buoy in 7 m water for 1 month (April 2008) to collect reference current and wave data to evaluate the performance of the buoy wave gauge in the small, short waves common to the region, and to understand how buoy motion affects the fidelity of the current measurements. Over 75% of the total current velocity energy was well described by a regional tidal model. The buoy-mounted current profiler compared well with the bottom-mounted current profiler in both speed and direction at all depth cells. For all currents greater than 0.1 m/s, the mean of the absolute value of the difference in current magnitude was less than 0.01 m/s. The mean of the absolute value of difference in current direction was 5°. An analysis of average intervals demonstrated that an average interval of 2 minutes achieved 96% of the best possible measurement compared to a 10 minute average. Significant wave height ranged from 0.1-0.7 m and peak periods varied from 2-4 s. The buoy mounted wave gauge reported wave period accurately, but may under-report significant wave height. Wave direction between the buoy and AWAC agreed well for all waves greater than about 0.25 m.**

I. INTRODUCTION

The Chesapeake Bay Interpretive Buoy System (CBIBS) collects real-time measurements of currents and directional waves from a series of small buoys designed for coastal regions. The CBIBS buoys provide real-time oceanographic, meteorological, and water quality measurements to a public website (http://www.buoybay.org/) every 1 hour. The targeted user demographics include commercial and recreational boaters, commercial and government resource managers, academic researchers, teachers, and students.

Perhaps the largest user group are recreational boaters setting out in vessels ranging from small canoes and kayaks to small motorboats and sailboats. For these users, getting accurate measurements of current velocity, as well as wave height, period, and direction are very important. Novice boaters may have trouble paddling or sailing into a 0.5 m current. Even relatively small waves of 0.5 m can make for a wet and dangerous ride in a small boat if the wave period is 2.0 s or less.

Every oceanographic buoy has a specific response to waves and currents depending on many factors, including its specific size, shape, ballast, and mooring. This response may affect the accuracy of current and wave measurements made from the buoy platform. It is important to validate these oceanographic measurements and consider how such options as sample rate and average interval may be configured to optimize both accuracy and power draw. Empirical relationship can be calculated for specific buoys at specific sites and used to correct for any possible errors or offsets in future deployments.

II. EXPERIMENT

A 1-month long experiment was conducted in an effort to evaluate the performance of the buoy mounted current profiler and directional wave gauge. An AWAC bottom-mounted current profiler and directional wave gauge was used as a reference. The buoy and AWAC were deployed adjacent to each other in 7 m of water in the central part of the Chesapeake Bay, Maryland, near the mouth of the Patapsco River (39°09.114' N, 76°23.472' W). The deployment lasted from 27 March 2008 to 30 April 2008.

The buoy hull used by CBIBS is manufactured by Tideland Signal (model SB-138P Sentinel) and has a 1.75 m diameter and weighs 454 kg in air. The anchor is a stack of three steel railroad wheels with a combined weight of about 1000 kg, with enough 1" mooring chain for a 2.5:1 scope connected to a 2 m chain bridle with swivel. The buoy is made of rotationally molded polyethylene with expanded polystyrene inside for strength and durability. The ballast is concrete and internal braces are made from stainless steel. This construction produces very little magnetic signature and allows for accurate directional measurements for the current profiler and wave system. Waves are measured with an AXYS Technologies TRIAXYS directional wave sensor. Current velocities are measured with a downward looking 1 MHz Nortek Aquadopp Profiler.

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Fig. 1 Buoy with AXYS Technologies TRIAXYS directional wave sensor
and a downward looking 1 MHz Nortek Aquadopp Profiler.

In an effort to evaluate buoy motion and optimize the current measurement average interval, the buoy-mounted Aquadopp Profiler was configured to sample velocity profiles and engineering data (pitch, roll, heading, etc) at 1 Hz for the last 10 min of each hour with a 1 m cell size. Similarly, the bottom mounted AWAC was configured to log current velocity profiles at 1 min intervals continuously over the entire deployment period with a 1 m cell size.

The Aquadopp Profiler was mounted in the buoy with the transducer head 0.5 m below the water surface. A 0.5 m blanking distance was used so that the first measurement cell began about 1.0 m below the water surface. The mounting height and blanking distance of the bottom mounted AWAC was adjusted so that the measurement cells would be co-located in the vertical with the Aquadopp Profiler. In a water depth of 6-7 m, there were 4-5 velocity cells of valid data for both systems. We have selected to study four cells in this report. Table 1 indicates the comparable cells with reference to the surface.

TABLE I
CELL NUMBER AND LOCATION FOR EACH SYSTEM

Aquadopp Cell	AWAC Cell	Location
1	4	Near Surface Cell
2	3	Next Down Cell
3	2	Next Down Cell
4	1	Near Bottom Cell

The buoy mounted TRIAXYS system measured waves over a 20 minute burst window during the last 20 minutes of each hour with a sample rate of 1 Hz. The bottom mounted AWAC measured waves over a 17 minute burst window beginning at the top of each hour. This staggered wave measurement interval was used because the buoy measured waves and currents and the same time and the primary goal of the experiment was to compare current measurements between the buoy and the AWAC, so it was more important to have the current measurements aligned over the last 10 minutes of each hour.

III. RESULTS

The flow regime in this region is dominated by semi-diurnal tides with a typical magnitude of 0.3 m/s. A tidal analysis using the Matlab utility T_TIDE (the principle eight tidal components) was used to compare the current velocities obtained by both the Aquadopp Profiler mounted in the buoy and the bottom mounted AWAC, with the predicted tidal currents at the study site [1]. Results of the tidal analysis suggest that over 75% of the total velocity energy is well described by a regional tidal model. The tidal model demonstrates that current velocities measured from the buoy agree within 1° of the primary tidal axis orientation. Table 2 offers results from the tidal analysis for cells 1-4 for both systems.

Source	Tidal Variability Aquadopp	Tidal Variability AWAC	Tidal Axis Aquadopp	Tidal Axis AWAC
Near Surface Cell	76.7%	80.7%	11.3°	10.3°
Next Down Cell	79.7%	84.7%	11.8°	11.5°
Next Down Cell	81.8%	80.1%	14.7°	13.9°
Near Bottom Cell	75.4%	73.6%	17.5°	15.9°

The buoy-mounted current profiler compared well with the bottom-mounted current profiler in both speed and direction at all depth cells. At the near-surface cell, the mean of the absolute value of the difference in current magnitude was 0.001 m/s, with a standard deviation of 0.022 m/s (Fig. 1). The mean of the absolute value of difference in current direction for the near-surface cell was 7.9°, with a standard deviation of 12.0° (Fig. 2).

Because current direction becomes "variable" at low magnitudes, and is ambiguous when the magnitude equals zero, the same analysis was only performed on currents with magnitudes greater than 0.1 m/s (0.19 knots). The mean of the absolute value of difference in current direction for the near-surface cell was 4.4°, with a standard deviation of 3.9°. Table 3 provides a summary of the magnitude and direction analysis. A further analysis of current magnitude and direction accuracy shows no relation to increased buoy motion and wave height for this buoy at this location.
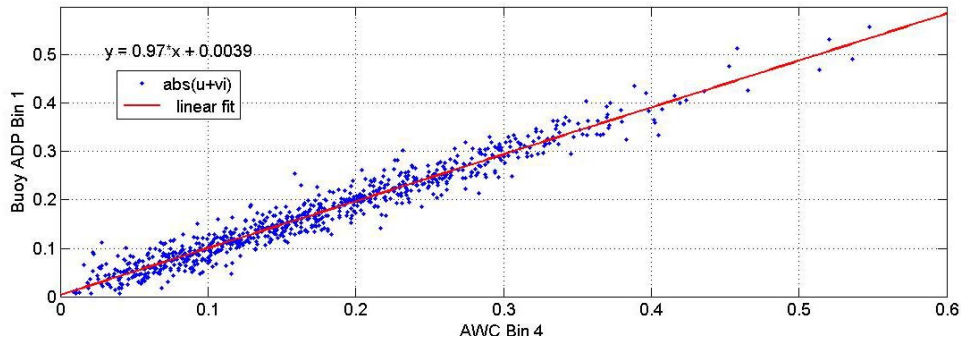

Fig. 1 Current magnitude of AWAC (bottom mounted) vs. Aquadopp Profiler (buoy mounted). Units in m/s.
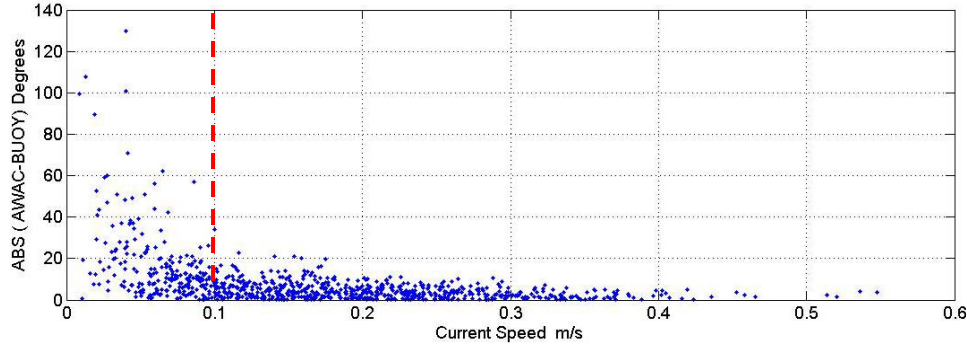

Fig. 2 Absolute value of the difference in current magnitude (AWAC-Aquadopp Profiler) as a function of current magnitude.
Red dashed line (0.1 m/s) indicates magnitude threshold for subsequent analysis.

TABLE III
QUANTITATIVE EVALUATION OF CURRENT MAGNITUDE AND DIRECTION FOR ALL MAGNITUDES GREATER THAN 0.1 M/S

Source	Magnitude (m/s)		Direction (deg)	
	Mean	STD	Mean	STD
Near Surface Cell	0.001	0.022	4.4	3.9
Next Down Cell	0.005	0.025	4.7	5.0
Next Down Cell	0.005	0.026	5.0	5.5
Near Bottom Cell	0.002	0.028	6.7	9.8

Determining the optimum average interval (i.e. the best compromise between velocity accuracy and power consumption) was possible by analysis of the 10 minute periods of 1 Hz velocity data collected by the Aquadopp Profiler. At some point the solution converges on the best possible accuracy and more sampling (averaging) would only consume more power. The 1 Hz velocity data from the V component (North/South) of the Aquadopp Profiler at cell 1 was compared to the 10 minute mean velocity from the reference AWAC. Figure 3 shows the classic curve of how error decreases with increased average interval approaching an asymptote, where increased averaging does not provide substantial improvements compared to the coincident increased power consumption.
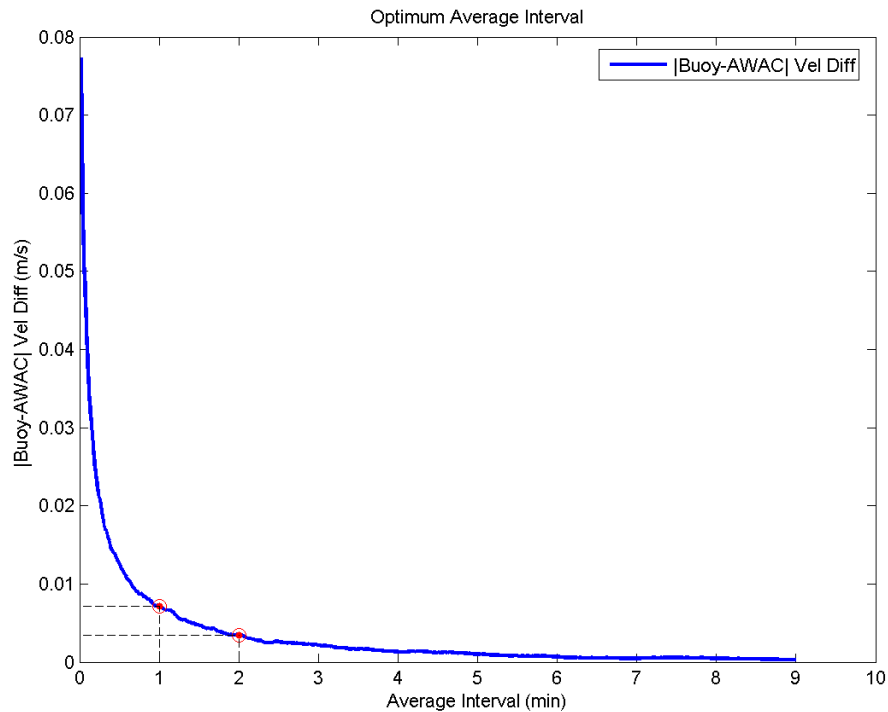
Fig. 3   Analysis of optimum average interval to minimize both error and power consumption.

The results indicate that 1 minute of averaged Aquadopp Profiler data from the buoy provide less than 0.01 m/s error (velocity difference) and achieves 91% of the best possible velocity. Averaging for 2 minutes provide less than 0.005 m/s error and achieves 96% of the best possible velocity. A further analysis on this optimization suggests that, for this buoy and location, the optimum average interval is a robust number and is not affected by increased wave height or buoy motion.

The significant wave height measured at the buoy and AWAC ranged from about 0.1-0.7 m (maximum wave height measured was 1.2 m) and the peak periods varied from about 2-4 s (Fig. 4). The buoy mounted wave gauge reported the wave period accurately, but under-reported the significant wave height by a factor of between 30-50%. Wave direction between the buoy and AWAC agreed well for all waves greater than about 0.25 m.
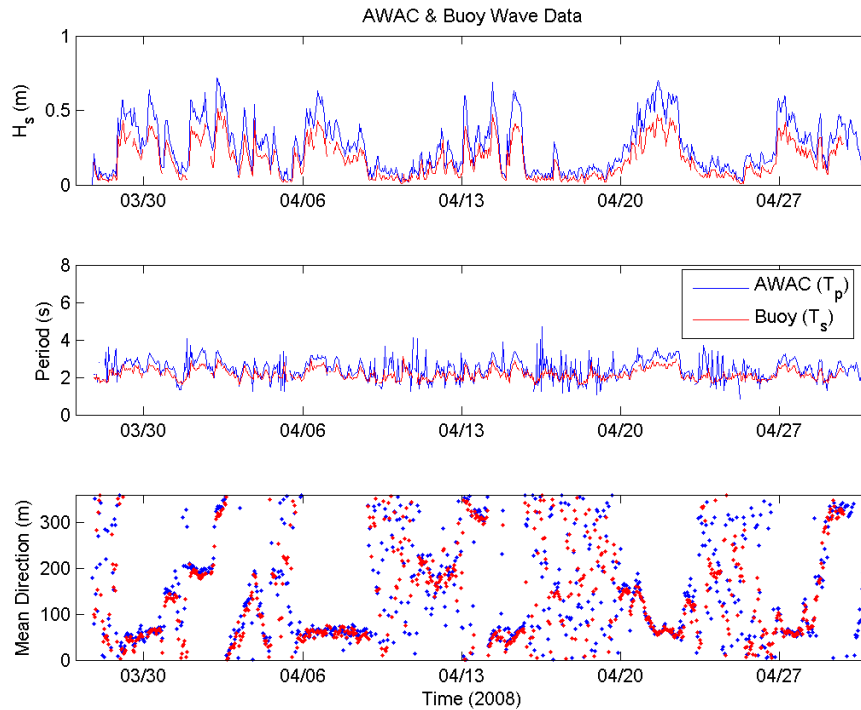

Fig. 4   Wave parameters measured by the AWAC (bottom mounted) and the TRIAXYS (buoy mounted).

IV. DISCUSSION

The richness of the data during this experiment allowed for some excellent comparisons and analysis with which to evaluate the performance of the Tideland Signal buoy for current and wave measurements in support of the CBIBS real-time observation program.

In particular, it was nice to compare the difference in current magnitude and direction between the buoy mounted profiler and the bottom mounted profiler for the non-magnetic plastic buoy. This analysis shows improved agreement between the buoy-mounted and bottom-mounted profilers in both magnitude and direction compared to a similar analysis of current data collected on the NOAA Physical Oceanographic Real Time System (PORTS) system where the Aquadopp Profiler is mounted on a steel Coast Guard Aid-to-Navigation (ATON) buoy. For the plastic Tideland Signal buoy, the mean of the absolute value of difference in current direction for the near-surface cell with magnitudes greater than 0.1 m/s was 4.4°, with a standard deviation of 3.9°. In contrast, the mean of the absolute value of difference in current direction for the near-surface cell with magnitudes greater than 0.15 m/s for the steel ATON buoy (with a large magnetic signature) was 8.7°, with a standard deviation of 7.3° [2].

The same NOAA PORTS program reports current velocity measurements calculated over a 5 minute average. The 5 minute protocol is not an empirically deduced requirement. It was selected as a best-guess for what is needed to get accurate data from a moving buoy [*pers. comms.* NOAA Staff]. Certainly, there is nothing wrong with a long average interval, but a shorter average interval may provide nearly the same accuracy and yet reduce the power requirements and provide for extended deployments without the need for more frequent service intervals. This study suggests that averaging data from a moving buoy at this site for 2 minutes achieves 96% of the accuracy compared to averaging for 10 minutes and provides an error of less than 0.005 m/s. If the NOAA PORTS program were able to reduce their averaging from 5 minutes to 2 minutes, then they would greatly reduce their power requirements and be able to deploy the system for about twice the amount of time between service intervals.

The buoy mounted wave gauge reported the wave period and direction accurately. The directional accuracy was impressive considering the relatively large size of the buoy compared to the small, short waves at the study site. The buoy wave gauge under-reported the significant wave height by a factor of between 30-50%. This is not surprising considering that the buoy weighs nearly 500 kg and the waves were relatively small and of short period. However, while 50% of the typical 0.7 m wave may be considered a small difference in absolute wave height (0.35 m = about 1 foot), this discrepancy is very important to the local user community (recreational boaters in small, open craft), especially considering the short period which makes the waves steeper.

The next step is to place the Tideland Signal buoy into a wave tank and make measurements in a variety of wave conditions to generate an empirical table that can be used correct the buoy wave height data in post-processing. While this table will not be specific for every buoy at every location, it will be a good start to getting better wave height measurements with this buoy at this location in the Chesapeake Bay.

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